

# Managing Infrastructure Problems That Arise From Earthquakes

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This article is a compilation of information on infrastructure problems that arise from earthquakes. It outlines the measures needed to determine what went wrong during such disasters and how to prevent future problems. Understanding the effects of earthquakes can help make the infrastructure safer and less prone to damage.

Earthquakes are inevitable, but the damage they cause is not. Taking control of the environment can help make homes and workplaces safer. This will be illustrated using four famous earthquakes as examples, preceded by a discussion of earthquake-related damage.

## Earthquake-Related Damage

Earthquake-related damage and casualties in Northern California result from seismic shaking, which often causes landslides, lateral spreads, ground settlement, and surface cracks. Damage increases markedly with a greater Richter magnitude. Two factors

have an important influence on ground failure: geologic, hydrologic, and topographic setting, and distance from the causative fault. Areas especially vulnerable to ground failure in Northern California include oversteepened slopes, mountain cliffs, stream banks, lowland deposits, and poorly compacted fills. It appears that liquefaction has been the direct cause of nearly all lowland failures.<sup>1</sup>

T. Leslie Youd, a world-renowned expert on soil liquefaction, contends that work in this field shows that ductile steel has experienced some damage during recent earthquakes. In addition, it is known that other disruptive conditions have occurred where steel was corroded—for example, on bridges and pipelines. Corrosion can provide points of weakness susceptible to damage during moderate-to-large earthquakes. These weak areas have been especially vulnerable to damage due to ground failures. Historical information suggests that future earthquakes may occur at the same locations as previous earthquakes.<sup>2</sup>

Frank E. Rizzo, an educator and authority in the fields of corrosion and metallurgy, suggests, “Any stress riser caused by corrosion would make the pipeline more susceptible to brittle fractures in sudden loading, such as earthquakes.”<sup>3</sup> Glade Hall, a chemical engineer, clearly reinforces the importance of cathodic protection on metals when he says, “Most corrosion occurs as local cells, as electrons migrate away from the iron molecules. Iron ions are left to combine with oxides and sulfides. This results in weakened steel from corrosion and brittle weld metal. Earthquakes systematically bring out the mistakes made in design, construction and maintenance—even the most minute mistakes.”<sup>4</sup> At a Utah Seismic Safety Commission meeting, Youd stated, “Older, corroded pipes may be susceptible to shaking damages during earthquakes.”<sup>2</sup> He pointed out that experience shows a high probability of damage from the weakened strength

**FIGURE 1**



San Francisco in flames after 1906 shock. Fire-fighting efforts were hampered by the unavailability of water, a consequence of the many major pipeline breaks that were caused by ground failures. Photo courtesy of the P.E. Hotz Collection, U.S. Geological Survey (USGS).

of steel pipelines or pipeline structures during seismic hazards from earth vibrations caused by earthquakes. The following four examples illustrate the type of damage caused by earthquakes as well as strategies to mitigate such effects.

## Earthquake Examples

### 1906 SAN FRANCISCO (CALIFORNIA) EARTHQUAKE

The most perilous natural hazards affecting northern California are earthquakes. One great (Richter magnitude  $[M] > 8$ ) and several major ( $M > 6$ ) earthquakes have struck that part of the U.S. during the last 200 years. These shocks and aftershocks have caused extensive property damage and inflicted several hundred casualties.<sup>2</sup> In fact, given the expanding population and construction of buildings, bridges, and pipelines, there has been an ever-increasing number of locations where an incident from an earthquake could have significant consequences. As a result, industry and government must do more just to maintain a low rate of serious accidents.<sup>4</sup> This rapid increase in population is enormous today compared with what existed in the past—and especially in 1906, the date of the last major destructive shock. In the 1906 earthquake, fires caused 85% of the damage in San Francisco.<sup>2</sup>

Soil liquefaction has a significant effect on structures. The Valencia Street liquefaction in San Francisco, California, on April 18, 1906, at 5:15 a.m. local time caused pipelines and structures to move 6 ft (1.8 m) laterally. Modern analysis estimates the 1906 earthquake had registered M 8.25 on the Richter scale. By comparison, the quake that hit San Francisco on October 17, 1989, registered M 6.7. Fires ignited by the 1906 event ravaged the city for more than 3 days before burning themselves out. In dealing with infrastructure problems, one need look no further than at buried utilities that lie together in the same trench under city

streets. One important characteristic of the shaking intensity noted in Lawson's (1908) report<sup>5</sup> is the clear correlation of intensity with underlying geologic conditions. At the Valencia Street location, the earthquake caused a settlement of from 6 to 8 ft (2.4 m) for a distance of from 150 to 200 ft (46 to 61 m) along this street. It simultaneously shifted the entire street, with adjacent lands, eastward through a maximum distance of 9 to 10 ft (2.7 to 3 m). This change in alignment and grade could, of course, mean nothing less than the total destruction of all water and gas mains, electric lighting and telephone conduits, sewers, cable conduits, railroad tracks, etc. The destruction of the water lines totally cut off water to a large portion of the city that soon was engulfed in flames (Figure 1).<sup>6</sup>

Areas situated in sediment-filled valleys sustained stronger shaking than nearby bedrock sites, and the strongest shaking occurred in areas where ground reclaimed from San Francisco Bay failed in the earthquake. You concluded, "Modern seismic-zonation practice [government zoning practices] accounts for the differences in seismic hazard posed by varying geologic conditions."<sup>2</sup>

### 1971 SAN FERNANDO (CALIFORNIA) EARTHQUAKE

The liquefaction caused by the February 9, 1971, San Fernando, California, earthquake—also known as the Sylmar Earthquake—caused both fissures and ground displacements. Despite its registering only M 6.7 on the Richter scale, it was the strongest

earthquake ever recorded in California in terms of motion up to that time. (The Richter scale measures only the total energy released and not other factors such as motion.) The Sylmar fault-

**FIGURE 2**



1971 San Fernando, California, earthquake where utility lines—gas, water, sewer, telephone, and electricity—were disrupted in the areas of most intense ground motion. Gas and other pipes failed where they crossed the zones of surface faulting. Photo courtesy of the USGS.

FIGURE 3



Both gas and water pipes burst beneath Balboa Boulevard north of the Simi Valley Freeway from the force of the main shock, creating this bizarre and destructive combination of fire and water. Photo © copyright Kerry Sieh, California Institute of Technology. Photo reprinted with permission.

FIGURE 4



Tipped building in Adapazari, Turkey, caused by liquefaction-induced loss of bearing strength during the 1999 Kocaeli, Turkey earthquake. Photo courtesy of T.L. Youd.

ing was recorded as a thrust. Craters from gas line breaks and flooding from water line breaks occurred following ground displacement beneath the San Fernando Juvenile Hall. During liquefaction, the induced lateral spreads caused pipes to suffer the greater damage.<sup>7</sup> Death and injury in an earthquake are caused primarily by partial or total collapse of man-made structures. Gas, water, sewer, telephone, and electricity lines were disrupted in the areas of the most intense ground motion (Figure 2). Pipes that failed crossed through the zone of surface faulting

(Figure 2).<sup>8</sup> Both California Governor Ronald Reagan and U.S. President Richard Nixon declared San Fernando a state of emergency and a national disaster.<sup>9</sup>

This disaster led to two important findings. First, it showed that there is a need for better, more comprehensive information on the accumulation of strain. Such data provides a better estimate of the frequency and magnitude of earthquakes in particular localities and on particular faults than can be obtained strictly on the basis of historical seismicity.<sup>8</sup> Second, it highlighted the need to strengthen building codes in populated areas.

In response to the Sylmar Earthquake, building codes were strengthened. In addition, the California Legislature passed

the *Alquist Priolo Special Studies Zone Act* in 1972. The purpose of this act was to prohibit the location of most structures for human occupancy across the traces of active faults, thereby mitigating the hazard of fault rupture.<sup>10</sup>

### 1994 NORTHRIDGE (CALIFORNIA) EARTHQUAKE

This earthquake clearly revealed how our society and our way of life depend on a complex network of infrastructure systems. These systems are our lifelines, providing us with utilities, transportation services, highways, and

roads. In this earthquake, even the airports were affected. In the early morning of January 17, 1994, a M 6.7 earthquake shook the Los Angeles (Northridge) area. Several buildings and freeway bridges collapsed, killing some 71 people and injuring thousands. Damage estimates were from \$40 to \$42 billion.<sup>11</sup> The Northridge Earthquake ruptured gas and water pipelines alike, causing flames to shoot up out of flowing water (Figure 3). The earthquake occurred on a blind thrust fault and produced the strongest ground motion ever instrumentally recorded in an urban setting in North America. Damage was widespread. Sections of major freeways, parking structures, and office buildings collapsed, and numerous apartment buildings suffered irreparable damage. On Balboa Boulevard, buried steel pipelines of high ductility survived the quakes. The older, corroded pipelines, however, failed. Well-built ductile structures do better under these conditions and often withstand the heavy shaking.<sup>7</sup> The Northridge Earthquake proved that even moderate events can cause billions of dollars of damage.

### 1999 TURKEY EARTHQUAKE

A devastating earthquake (M 7.4) occurred on August 17, 1999, in Kocaeli, Turkey, which is ~50 miles (80 km) southeast of Istanbul (Figure 4). A 2.2-m-diameter ductile steel water pipeline (ATI, API Grade B, mild structural steel)<sup>12</sup> crossed through the fault at a location where 3 m of fault displacement occurred. Although it was severely deformed, it continued to supply water after the earthquake. The Kocaeli earthquake provided a good example of how longitudinal compression affects pipelines. Longitudinal compression has been shown to be one of the most common causes of earthquake damage to pipelines. Once again, Youd cautions: "It is important to avoid, if possible, putting critical structures through the fault line. By learning from failures, improved con-

struction practice codes may save lives in future earthquakes." He continues, "The Kocaeli earthquake shows that shortening or pipe compression due to ground displacement is a serious design problem as it relates to zoning practices, architectural planning, and on-site building procedures. In this earthquake, some modern ductile pipelines, however, withstood ground displacement."<sup>7</sup>

## Conclusion

The level of concern about earthquakes is often questioned. It is important to understand what can be expected. The examples discussed in this article encourage earthquake awareness and preparedness by describing the hazards faced by those in seismically active areas. Not taking measures to prepare for an earthquake may stem from fear, denial, or ignorance. The ultimate lesson is that building and development is more than a simple physical process. Governmental institutions and social processes must develop in parallel to keep up with the physical demands and assure minimum acceptable standards of construction and public safety.

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